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Are Western Australian waters the least productive waters for finfish across two oceans? A review with a focus on finfish resources in the Kimberley region and North Coast Bioregion

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Abstract

The marine ecosystems of Western Australia, including those in the Kimberley, are classified as being of moderate to low productivity. This is primarily a consequence of the influence of the Leeuwin Current, the eastern boundary current that flows poleward delivering warm, low nutrient waters, and only sporadic short-term upwelling events to shelf habitats off the Western Australian coast. This, coupled with little riverine inflow from old weathered terrestrial systems, results in low levels of primary and secondary production in habitats along most of the coast. The consequence is that finfish fisheries in the Kimberley and throughout the State typically land a diverse range of long-lived species with low levels of productivity, resulting in relatively low levels of sustainable catches. The consequences for monitoring, management and stakeholder aspirations are presented. Additional challenges for finfish fisheries in the Kimberley and North Coast finfish fisheries are also discussed.

Keywords: fisheries, finfish, productivity, Western Australia, Kimberley, North Coast Bioregion

Introduction

Western Australia's coast extends more than 12,800 kilometres from the Northern Territory border, west to the South Australian border. The waters of Western Australia extending out to the Australian Exclusive Economic Zone (EEZ) represent approximately one third of the Australian EEZ, or approximately 2 million km^2 of ocean between 10°- 40°S. Within these waters there are more than 20 State-managed commercial finfish fisheries that operate from the North Coast Bioregion (which includes the Kimberley) targeting tropical species such as barramundi, red emperor and Spanish mackerel through to southern fisheries targeting species such as pilchards on the West Australian side of the Great Australian Bight (DoFWA 2011, see also Fletcher and Santoro (2010) for details). Throughout this range there are also extensive recreational fisheries including recreational-only fisheries off the coast of Perth and within the Shark Bay World Heritage Area and areas of high levels of recreational effort such as Roebuck Bay immediately south of Broome.

In addition to the State-managed fisheries, there are also fisheries managed by the Australian Fisheries Management Authority (AFMA, see Wilson *et al.* (2010) for details), including three deep-water trawl fisheries that also capture finfish off the coast of Western Australia; the North West Slope Trawl Fishery off the Kimberley and Pilbara Coasts; the Western Deepwater Trawl Fishery off the Gascoyne and West Coasts; and the Great Australian Bight Trawl Fishery along the South Coast. There are also two Joint Authority fisheries (the Joint Authority Northern Shark Fishery which operates in the Kimberley and the Joint Authority Southern Demersal Gillnet and Demersal Longline Fishery, (see Fletcher and Santoro (2010) for details) for which management responsibility is shared between the Commonwealth, State and adjacent Territories. Australia is also a member of the Indian Ocean Tuna Commission (IOTC, www.iotc.org) and Australian-flagged vessels can operate within the waters of the Australian EEZ off the Western Australia coast to target tuna, billfish and other permitted species.

The extensive ocean area off the West Australian coast and large number of fisheries can lead to the perception that there are extensive finfish fishery resources to be exploited. However, the total finfish (*i.e.* scalefish and elasmobranchs) production for Western Australia is globally modest (Lenanton *et al.* 2007). For example, since 1988/89 annual finfish catches for all State-managed fisheries have fluctuated between 2,500 tonnes to 24,000 tonnes, averaging approximately 15,000 metric tonnes per year (t.yr^{-1}) over the last decade, with a recent decline (Fig. 1). The average production is approximately 130 t.yr^{-1} per 100 km of coastline, not including recreational fisheries. Peak catches were recorded during the period 1996–1998, at the height of the southern purse-seine fishery for small, relatively short-lived pelagic species (mainly pilchards, *Sardinops sagax*) immediately

Figure 1. Map of Western Australia showing the extensive coastline, latitudinal range and the four marine and two inland Bioregions in the State. Source: Fletcher & Santoro (2010). The Kimberley area is approximately north of 20°S and east of 120°E.

prior to the collapse of the fishery due to the herpes virus in the mid to late 1990s (Whittington *et al.* 2008), which resulted in biomass reductions of up to 75% (Gaughan *et al.* 2000). The Kimberley fisheries, while increasing, have only recently exceeded 1,000 metric tonnes $t.yr^{-1}$.

In addition to State managed fisheries, fisheries managed by AFMA have also reported modest catches. For example, the North West Slope Trawl Fishery targets invertebrates but has reported approximately 130 $t.yr^{-1}$ of fish (as discarded bycatch) between 2000 and 2008 (Emery *et al.* 2009a). The Western Deepwater Trawl Fishery, which targets finfish and invertebrates, has reported total finfish catches of up to 320 $t.yr^{-1}$ (in 2001); however more recent catches have declined with less than 20 $t.yr^{-1}$ reported between 2004 and 2006 (Emery *et al.* 2009b). The most recent data available (Wilson *et al.* 2010) shows that the annual retained scalefish catch from these fisheries is well below 100 $t.yr^{-1}$. The highest annual catch reported for an individual species was 885 tonnes of deepwater flathead landed by the Great Australian Bight Trawl sector in 2009/10. However the area of intensive fishing straddles the WA/SA border, and the proportion of this catch taken in West Australian waters was not reported. Declines in fishing effort have also been reported in other AFMA managed fisheries operating off the coast of Western Australia (Table 1). Finfish catches by the Joint Authority fisheries operating off the coast of Western Australia are included in the catches reported in the State (see Fletcher & Santoro 2010). Thus, the combined catches of these Commonwealth managed fisheries adds a relatively small amount to the total catches in waters off Western Australia.

Historically, trawlers from distant water fishing nations also operated off the coast of Western Australia, principally in the Kimberley and Pilbara areas between 1980 and 1990 (Nowara & Newman, 2001). While these trawlers operated throughout extensive areas of the North Coast Bioregion, the limited data available indicates that catches were modest and not likely to be profitable to sustain these fleets. Since the mid 1990s, the waters of the Australian EEZ have been reserved exclusively for Australian fishing vessels, only limited Commonwealth trawling has been reported in the North Coast Bioregion, producing modest catches (Table 1).

Additionally, many of the State managed fisheries operating off Western Australia either have a recent history of declining catches (*e.g.* WCDSF, Wise *et al.* 2007; Fairclough *et al.* 2010), and/or reduced levels of effort due to risks to biological sustainability of fish stocks and resources (Fairclough *et al.* 2010; Newman *et al.* 2010c), while the Commonwealth managed fisheries are characterised by relatively high levels of unused (latent) effort or licenses (*e.g.* Rodgers *et al.* 2010; Sampaklis *et al.* 2010). Thus most commercial finfish fisheries operating in WA waters are considered fully-exploited, or have large amounts of entitlement not being used likely due to the non-viability of profitable fishing.

This paper aims to define the productivity and fisheries in Western Australia in a wider context with a focus on finfish fisheries operating in the Kimberley region. The relatively low productivity of finfish resources are discussed in relation to the implications for monitoring, management and stakeholders in the State. Additional challenges for finfish resources and exploitation in the Kimberley and North Coast Bioregion are also presented.

How large are WA fisheries relative to other locations?

Three examples have been selected to put the total catches and productivity of finfish resources of WA in a broader context. Barramundi (*Lates calcarifer*) are captured throughout the Kimberley and northern Australia, from the Pilbara (Fig. 1) in northern Western Australia, throughout the Northern Territory and tropical Queensland. Commercial catches in Western Australia from approximately 4,000 km of coastline have varied between 27 and 60 $t.yr^{-1}$ since 1999 (Newman *et al.* 2010b). In comparison, the Northern Territory landed 588–665 $t.yr^{-1}$ and Queensland 880–1,071 $t.yr^{-1}$ (2006–07 to 2008–09 catches, ABARE–BRS 2010). The WA fishery is approximately one order of magnitude smaller than other barramundi fisheries in Australia despite an extensive coastline.

Pink snapper (*Pagrus auratus*) is a demersal species targeted by both commercial and recreational anglers in Western Australia. This species is also found throughout the temperate and subtropical regions of Australia and New Zealand. In WA pink snapper are fished from north of Carnarvon (Fig. 1) to the south Australian border (at least 2,800 km). The total West Australian catch of pink snapper is approximately 600 $t.yr^{-1}$ (Fletcher & Santoro 2010). In comparison, the New Zealand Snapper Area One (SNA1) fishery (north of Auckland) has an annual

Table 1

Summary of recent catch data for Australian Fisheries Management Authority (AFMA) managed fisheries operating in the waters off the coast of Western Australia. (t, metric tonnes; AFZ, Australian Fishing Zone).

Fishery	Relevant component to Western Australia	Recent catch data	Comment	Source
Small Pelagic	B-zone	Not available	Too few vessels operating to release data for B-zone	Wilson *et al.* 2010, pp 131–146; www.afma.gov.au
Great Australian Bight Trawl Sector	Operates between 115°08'06"E Cape Leeuwin WA) and 138°08'05"E (Cape Jervis, SA)	2007/08 catch 3,712 t; 2008/09 catch 1,630 t; 2009/10 catch 1,556 t. 10 permit holders, 4 active in 09/10.	Proportion of catches taken in waters off Western Australia not reported	Wilson *et al.* 2010, pp 232–249; www.afma.gov.au
Western Skipjack Tuna	From 142°30'E (Cape York), west to the South Australian Border (Encompassing waters of the Gulf of Carpentaria, Northern Territory, Western Australia and South Australia)	406 searching hours was reported from this fishery in 2008/09. Total catch, 885 t. 13 permit holders but only 2 active in 2008/09.	Very low levels of activity in this fishery.	Wilson *et al.* 2010, pp 411–421; www.afma.gov.au
Western Tuna and Billfish	From 142°30'E (Cape York), west to the South Australian Border (Encompassing waters of the Gulf of Carpentaria, Northern Territory, Western Australia and South Australia	2009, 93 permits but only 3 active. Catch, 455 t.	Between 2004 and 2009, 144.7 t of minor by-product retained, and 57,727 individuals (mostly sharks) discarded.	Wilson *et al.* 2010, pp 433–458; www.afma.gov.au
North West Slope Trawl	From 114°E to 125°E, between 200m isobath and AFZ outer boundary	2005/06 to 2008/09 136 t of minor byproduct retained, 22.6 t discarded. 7 permit holders but only 2 active in 2008/09.	Retained catch of scalefish very small.	Wilson *et al.* 2010, pp 119–130; www.afma.gov.au
Western Deepwater Trawl	From 115°08'E off the south coast to 114°E off the north coast.	2004/05 to 2008/09 72 t scalefish retained, 0.7 t discarded. 11 permit holders but only 1 active in 2008/09.	Retained catch of scalefish very small.	Wilson *et al.* 2010, pp 337–349; www.afma.gov.au

total allowable catch (TAC) of 7,500 t.yr^{-1} (http://fs.fish.govt.nz/Page.aspx?pk=7&tk=37&sc=SNA). The total snapper TAC for New Zealand is more than 10,000 t.yr^{-1} (http://fs.fish.govt.nz/Page.aspx?pk=7&tk=37&sc=SNA) for a 15,000 km coastline (fs.fish.govt.nz/Page.aspx?pk=45&tk=464). Western Australia catches of pink snapper are more than an order of magnitude lower than those for New Zealand, highlighting massive differences in productivity.

In a more extreme example, the total Western Australian catches of small pelagic fishes (mainly pilchards, *Sardinops sagax*) by the South Coast purse-seine fishery in its peak (1986–1997) was approximately 9,000 t.yr^{-1} (Molony & Lai 2010). In contrast, catches of an ecologically similar species, the Peruvian anchovy, *Engraulis ringens*, have ranged between 6.2 and 10.7 million t.yr^{-1} between 2003 and 2007 (FAO 2009); Western Australian record catches of small pelagic fishes could be taken within a single day in the Peruvian anchovy fishery off the west coast of South America between Valparaiso, Chile and Chimbote, Peru (approximately 3,200 km), making West Australian catches insignificant in comparison (Lenanton *et al.* 1991). In addition, comparisons with the adjacent South Australian fishery are notable. The South Australian Sardine Fishery has had annual catches between 29,854 and 31,577 t.yr^{-1} since 2007 (Ward *et al.* 2010).

Why the relatively small scalefish fisheries in Western Australia?

These three examples demonstrate that the Western Australian catches of many finfish species are relatively modest compared to catches of the same or similar species in other parts of Australia and the world. This raises the question; with such an extensive coastline and so much water, why are the catches so low? There are several reasons for this.

Globally, waters off Western Australia, including the Kimberley region, are generally of low to moderate primary productivity (Pearce *et al.* 2000), internationally classified as Class II (moderate: 150–300 gC.m^{-2}.yr^{-1}) or Class III (Low: <150 gC.m^{-2}.yr^{-1}) productivity systems (McGinley 2008a, b, c). The exception is the Class I high productivity (>300 gC.m^{-2}.yr^{-1}) ecosystem of northern Australia, from Cape Londonderry (Western Australia) east to Cape York (Queensland) (McGinley 2008d). However, this ecosystem accounts only for some 250 km (or 2%) of the coastline of Western Australia. The rest of

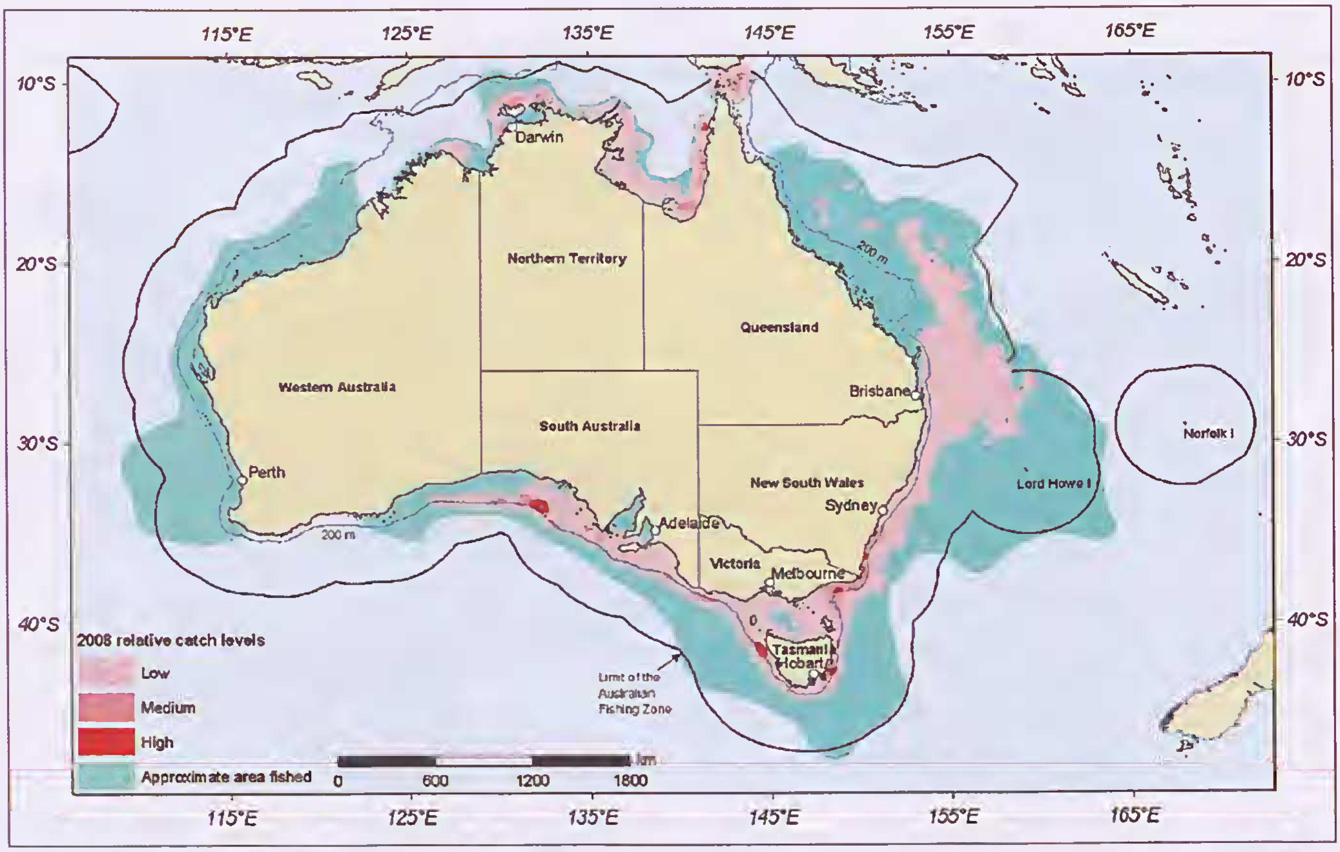

Figure 2. The relatively low levels of catches by Commonwealth Fisheries in waters adjacent to Western Australia are clearly shown by a national comparison of relative catch levels. Also note the areas where no Commonwealth catch (and therefore effort) was reported in 2008, despite these areas being open to a range of Commonwealth fisheries. Sources: Wilson *et al.* (2010) and www.daff.gov.au/__data/assets/image/0009/1373292/Relative-catch-levels.jpg

the West Australian waters are of low to moderate primary productivity, including the marine waters of the Kimberley.

The southward flowing Leeuwin Current dominates the oceanography along the Western Australian shelf (Lenanton *et al.* 1991, 2009). This low-nutrient current, which originates in the tropical Kimberley area, of Western Australia (Cresswell and Domingues 2009), runs poleward and limits the productivity of shelf waters, especially in temperate Western Australia (Godfrey & Ridgeway 1985; Caputi *et al.* 1996; Muhling *et al.* 2008). While there are localised and sporadic small-scale upwelling events (Lenanton *et al.* 2009), there is an absence of large, predictable, nutrient rich upwelling systems that are typical of other shelf systems along the eastern sides of ocean basins (Lenanton *et al.* 1991; Pearce 1991; *e.g.* the Canary Current, north-western Africa; the California Current, western North America, especially off California and Oregon; the Humboldt Current, north-western South America, especially off Peru and Chile).

Secondly, there is limited terrestrial input into ocean productivity off the Western Australian coast. Western Australia is the oldest part of the Gondwana land mass presently above sea level (Fig. 3), with ages of the continental crust in Western Australia ranging between 545 ma (million years of age) and 4,560 ma (en.wikipedia.org/wiki/Natural_history_of_Australia), allowing a long period of time for weathering and erosion to occur. This is evidenced by the relatively modest peaks and extensive low-lying areas in Western Australia, particularly in the north. The highest peak in Western Australia is in the north of the State, Mount Meharry in the Hamersley Range, approximately 1,250 m above sea level (Geosciences Australia, www.ga.gov.au/geodesy/ngdb). In the South West, the highest point is Bluff Knoll (1,070 m) in the Stirling Ranges. In contrast, the continental crust is much younger in Eastern Australia (Fig. 3) as the plate is being formed in the "rim of fire" in the Pacific Ocean off eastern Australia. As a result, in countries in the Pacific Ocean like New Zealand, Vanuatu and New Guinea, and in eastern Australia where the plate is much younger than in Western Australia, mountains are relatively high, some thousands of metres tall. Some mountains are high enough to gather snow at certain times and some even support permanent glaciers (*e.g.* in New Guinea, Hope *et al.* 1976).

A consequence of this long-term weathering is that the soils are extremely nutrient poor in many areas of Western Australia. These soils have been classified as Old, Climatically Buffered, Infertile Landscapes (OCBILs, Hopper 2009). As a consequence, there are very limited areas of high terrestrial productivity. For example, there are no extensive forests in the Kimberley region of Western Australia as there are in similar latitudes in North Queensland. Much of the northern areas of

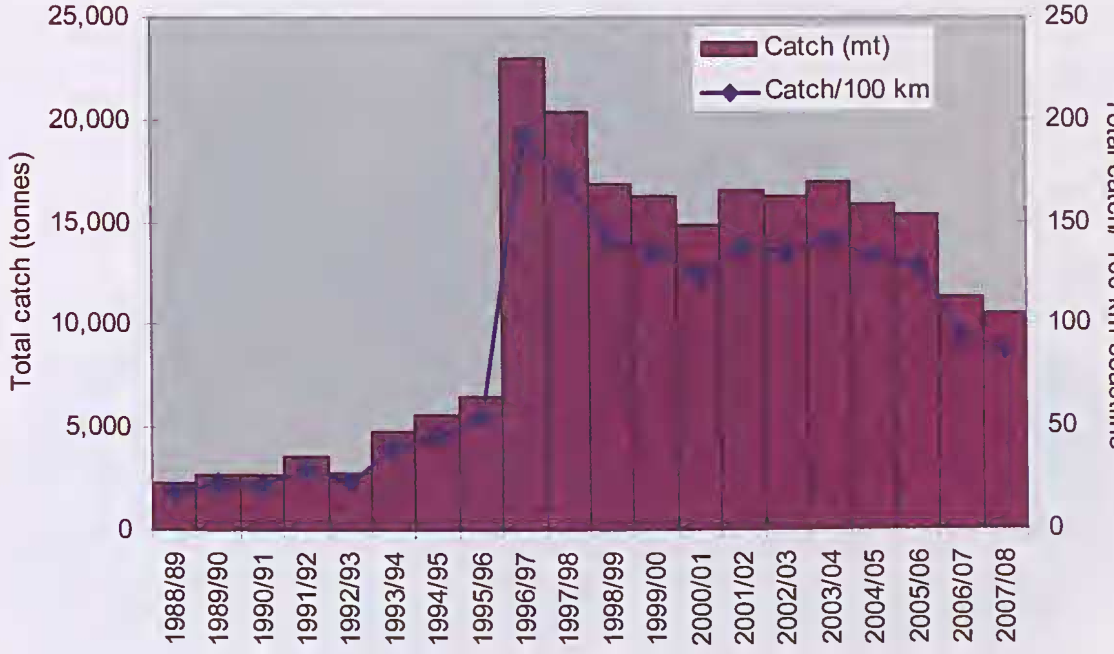

Figure 3. Total finfish production by Western Australia, 1988/89 to 2007/08. Source: Australian Bureau of Agricultural and Resource Economics (ABARE), www.abare.gov.au.

Western Australia are desert with low-lying scrub. In the south, while there are forests, they are not as extensive as in other places and are limited to the plains between the Indian Ocean and the relatively low Stirling ranges.

Additionally, with few mountains and extensive areas of relatively flat land, there are few catchments that support large rivers. The entire coastline of Western Australia has relatively few river systems, few wetlands and few coastal embayments (*e.g. cf.* Queensland). There are extensive areas of the coastline where no river crosses. For example, between Broome and Port Hedland there is approximately 400 kilometres of coastline without a permanent river that crosses the coast. Similarly, there are no rivers that cross anywhere along more than 500 km of coastline between Esperance and the Western Australia-South Australia border. These great distances of coastline without river systems highlight the low terrestrial input to the oceans, and thus low oceanic productivity off Western Australia

The low primary productivity results in modest concentrations of zooplankton. Comparisons with Southern Africa and South America show that secondary productivity in Western Australia is relatively low, between 50 and 200 $mg.m^{-3}$, including waters of the Kimberley region (Pearce *et al.* 2000). In other upwelling systems (*e.g.* South America), secondary productivity can be greater than 500 $mg.m^{-3}$, more than an order of magnitude higher.

The low levels of primary and secondary productivity limit scalefish production. Large upwelling systems typically support very large fisheries (hundreds of thousands of tonnes), including demersal scalefish fisheries. In the absence of large, regular upwelling systems (Pearce *et al.* 2000), the fisheries production in Western Australia is limited (Lenanton *et al.* 1991, Caputi *et al.* 1996, Muhling *et al.* 2008). Many demersal scalefish fisheries typically produce in the order of less than two thousand $t.yr^{-1}$ (Lenanton *et al.* 1991, 2007; Fletcher & Santoro 2010). Total production of short-lived pelagic species, such as pilchard (*Sardinops sagax*), are also relatively small, with peak annual catches being less than 10,000 $t.yr^{-1}$, insignificant to catches of similar species in the Humboldt Current off Peru (Lenanton *et al.* 1991).

An ecological consequence of limited productivity is high diversity (Hopper *et al.* 2009); no single species tends to dominate nutrient poor environments such as much of the marine systems in Western Australia. For example, in the Northern Demersal Scalefish Fishery at least 56 species of fish have been captured in traps, with more than 130 species recorded from video surveys (Newman *et al.* in review). Similarly, in the West Coast Demersal Scalefish Fishery more than 100 species have been reported in the catch of recreational and commercial fishers (Fairclough *et al.* 2010). With high diversity, the stock sizes of individual species are relatively small. In Western Australia, stock sizes of many demersal species are estimated in the hundreds or low thousands of tonnes per species (Fletcher & Santoro 2010) including in the Kimberley region and the North Coast Bioregion (Newman *et al.* 2010c).

An evolutionary consequence of a low productivity environment with high diversity is a shift towards long-lived species with a long period of maturity. In Western Australia, many demersal species supporting commercial and recreational fisheries have longevities greater than 25 years (Wise *et al.* 2007), including species in the Kimberley and North Coast Bioregion (*e.g. Lutjanus sebae*, 40 years (Newman *et al.* 2010a), *Pristipomoides multidens*, 30 years (Newman and Dunk 2003)) and temperate species (*e.g. Glaucosoma hebraicum*, 41 years (Hesp *et al.* 2002), *Pagrus auratus*, 41 years (Norriss & Crisafulli 2010)).

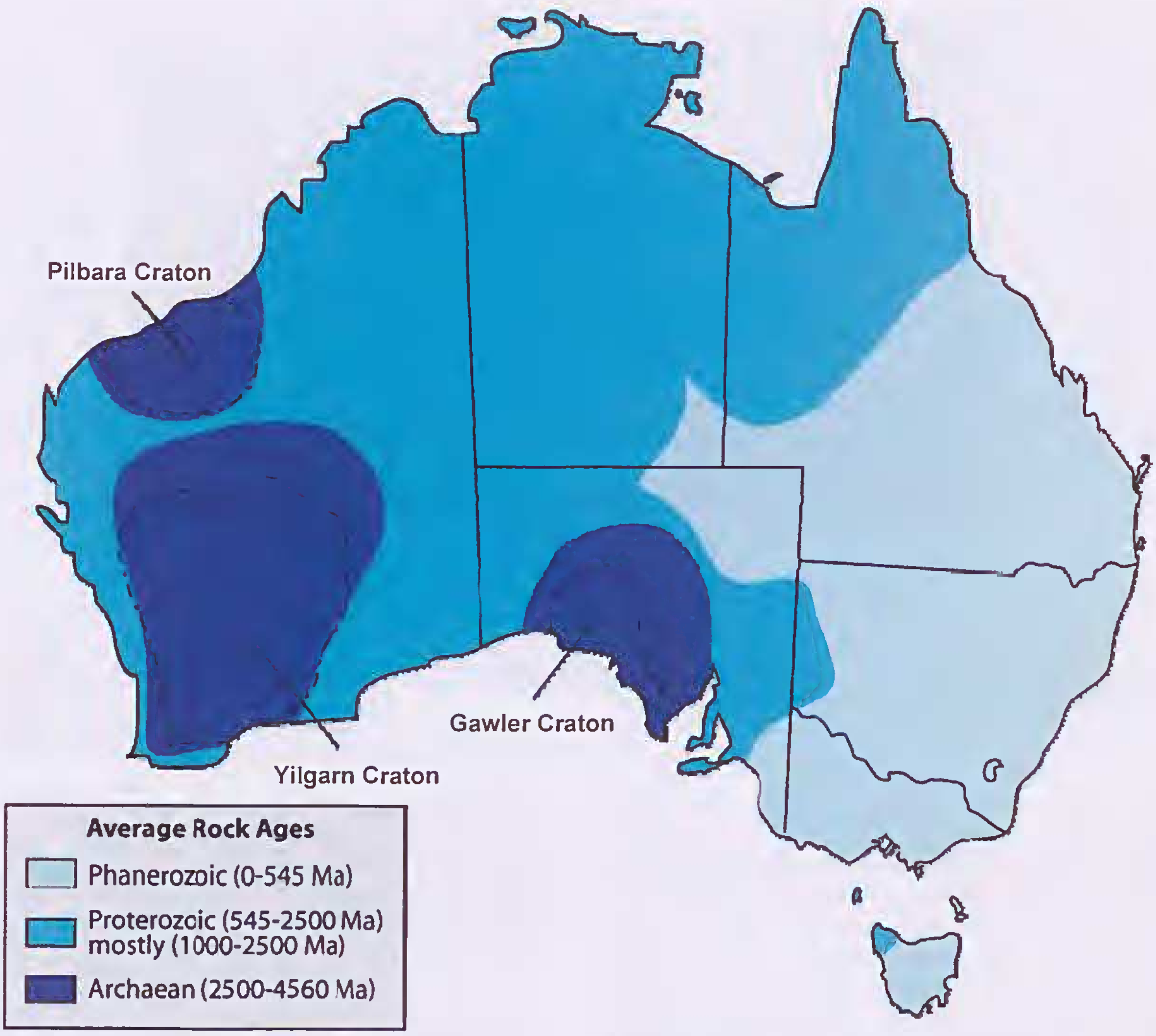

Figure 4. Map of Australia showing the ages (in millions of years, ma) of the continental crust. Source: en.wikipedia.org/wiki/Natural_history_of_Australia.

One hypothesis for evolution of a high longevity is to allow for a long period of sexual maturity. In environments with low productivity, a long period of maturity maximises the likelihood of reproduction during favourable conditions for a given species. Many of the demersal species in Western Australia mature at between 3–7 years (see Hesp *et al.* 2002; Newman & Dunk 2003; Newman *et al.* 2010a; DoFWA 2011), allowing these species up to several decades of reproductive activity. This allows an increased chance of spawning during periods where environmental conditions are favourable for a given species (Lenanton *et al.* 2009).

A further consequence of low productivity and long periods of sexual maturity is that there is typically variable recruitment. For example there have only been two (1999 and 2007) above average recruitment events in over a decade of monitoring pink snapper recruitment in temperate Cockburn Sound (C. B. Wakefield pers. comm.) and sub-tropical Shark Bay (G. J. Jackson pers. comm.). Additionally, variable recruitment resulting in strong recruitment every five to ten years may be sustaining a stock and therefore the fishery in some regions (*e.g. Glaucosoma hebraicum* Wise *et al.* 2007; Lenanton *et al.* 2009). As a consequence relatively few age classes may dominate catches that support much of the fishery exploitation (Wise *et al.* 2007).

Implications of low productivity finfish resources in Western Australian

Applying fisheries management over small stocks with these types of population dynamics means that there is only scope for a modest total sustainable fishery production on many stocks and resources. This is not a new finding. In the early 1900s, the survey vessel "*The Rip*" reported that with large areas of barren land, there was unlikely to be large finfish fisheries to be sustained in Western Australian waters (Oxley 1904).

The management implications of low productivity and small-scale fisheries are clear. Firstly the total productivity in terms of catches for many species of finfish will be relatively low. In WA, few species of scalefish have supported catches over 500 $t.yr^{-1}$ (see Fletcher & Santoro 2010) with the exception of pilchards and some other shorter-lived species (*e.g.* Australian herring, *Arripis georgianus*).

Given the high diversity, it is unlikely that significant large new fishery resources will be identified that could support large commercial or recreational fisheries. Most finfish fisheries are multi-species fisheries, typically relying on 10–15 species to account for 90% of catches (see Fletcher & Santoro 2010), with year-to-year variability among species that dominate catches. This applies to both State-managed and Commonwealth fisheries operating off the coast of Western Australia.

Additionally, most finfish resources in the State are likely to be fully exploited, with only modest scope for expansion. This is based on a long history of commercial fishing, initially with little restrictions or management limits. Despite the long history of commercial fishing, catches have only exceeded 20,000 $t.yr^{-1}$ in two years since the late 1980s, with catches in the last decade fluctuating between 10,000 $t.yr^{-1}$ and 15,000 $t.yr^{-1}$. In addition, recreational effort and catches have only recently been constrained yet catches in the West Coast Bioregion have been not exceeded approximately 300 $t.yr^{-1}$ despite a population exceeding 1.5 million in the metropolitan area, representing potentially hundreds of thousands of fishers.

Additionally, long-lived species, in low productivity environments result in fishery resources that are highly vulnerably to fishery impacts (*e.g.* recruitment overfishing, Stephenson & Jackson 2005). If stocks do become over exploited (*e.g.* Pink snapper in inner Shark Bay; Stephenson & Jackson 2005) recovery periods are in the order of a decade or more (Jackson *et al*. 2010). Initial modelling of over-exploited stocks in the West Coast Bioregion suggest that it may take 10–20 years to rebuild stocks of West Australian dhufish, *Glaucosoma hebraicum* (B. Wise, pers. comm.). A long period of recovery is also likely after non-fishery impacts. For example, in the relatively short-lived species (*e.g.* pilchards, *Sardinops sagax*, maximum age of nine years (Fletcher & Blight 1996)), stocks in Western Australia are still recovering after the herpes virus of 1998/9 (Gaughan *et al*. 2008), although catches are still below the peak of the mid 1990s.

Due to the high diversity of the finfish species that support fisheries, it is logistically and economically impossible to monitor or assess the status of all species; monitoring must be cost-effective relative to the value of the resource (economic, social and cultural values). To overcome this issue the Department of Fisheries Western Australia has identified species as indicators of the status of a suite of species (DoFWA 2011).

For example, for the inshore demersal finfish resources that support the North Coast Demersal Scalefish Fisheries (Northern Demersal Scalefish Fishery, NDSF, and the Pilbara Demersal Scalefish Fishery, PDSF), more than 100 species of finfish are landed. However, only five species – red emperor (*Lutjanus sebae*, NDSF and PDSF), goldband snapper (*Pristipomoides multidens*, NDSF and PDSF), rankin cod (*Epinephelus multinotatus*, PDSF), blue spotted emperor (*Lethrinus punctulatus*, PDSF) and brownstripe snapper (*Lutjanus vitta*, PDSF) – are currently directly assessed; the status of the these stocks are used to determine the status of the entire suite of inshore demersal fishes that support these fisheries (DoFWA 2011). These species were chosen due to a combination of their vulnerability, based on their life history characteristics and significance to commercial and recreational sectors (DoFWA 2011).

Similarly, for the 100 or more species that make up the inshore demersal finfish resources that support the West Coast Demersal Scalefish Fishery, only three species – pink snapper (*Pagrus auratus*), the West Australian dhufish (*Glaucosoma hebraicum*) and baldchin groper (*Choerodon rubescens*) – are directly assessed using age structure approaches to determine the status of the entire suite (DoFWA 2011). These three species were chosen due to a combination of their vulnerability, based on their life history characteristics and because both the commercial and recreational fisheries target these species (Wise *et al*. 2007; DoFWA 2011). Indicator species are also monitored for all fisheries in Western Australia (DoFWA 2011). The species monitored are periodically re-evaluated as fishery dynamics and management arrangements evolve.

This information must also be clearly communicated to all stakeholders, not only commercial fishers but recreational fishers and the wider community too. The key messages include;

- Waters of Western Australia are relatively low in terms of productivity
- As a result Finfish stocks, and total catches, will also be relatively small compared to fisheries in many other regions of Australia and the World
- Many of the finfish resources that support fisheries are composed of multiple species
- Many finfish species are long lived (25 + years), especially valuable demersal species
- These characteristics make the finfish resources vulnerable to impacts of fishing and environmental variability.
- If stocks are over-exploited, they will take long periods (in the order of decades) to rebuild under appropriate management arrangements.
- Stakeholder aspirations must be consistent with the potential of the finfish resources and the ecological systems that support them.
- There should also be no illusion that there is room for large-scale developmental fisheries or new fisheries in the order of thousands of tonnes; the waters of Western Australia simply do not support this scale of finfish resources.

Additional challenges for finfish resources in the Kimberley and North Coast Bioregion

The above information also applies to the finfish resources and fisheries in the Kimberley and the North Coast Bioregion. In addition, there are some additional features and challenges for finfish resources in these northern areas of Western Australia.

With the exception of a small extent (~250 km) of coastline east of Cape Londonderry to the Northern Territory border (McGinley 2008d), the entire North Coast Bioregion (including the Kimberley and the Pilbara) is a Class III, low productivity (<150 $g.C.m^2.yr^{-1}$) ecosystem (McGinley 2008a). Thus the total fishery productivity of the area is relatively low. While trawling and other method-based fisheries have been operating in the North Coast Bioregion for decades (Newman *et al.* 2010c), total catches have been relatively modest compared to the extent of the area fished.

Tidal ranges vary along the coastal region of the North Coast Bioregion, but include some of the largest tidal ranges in Australia (*e.g.* Broome (Kimberley): 10–12 m; Port Hedland (Pilbara): 7 m). These large water movements generate and maintain high levels of turbidity in coastal waters, which limit benthic productivity in marine systems. Coupled with a relatively low rainfall and a low productivity terrestrial system, the total marine productivity of the Bioregion is correspondingly low. This is reflected in the catches of commercial fisheries.

For example, the entire catch of demersal Scalefish in the North Coast Bioregion from Cape Londonderry to Onslow peaked at approximately 4,000 $t.yr^{-1}$ and more recent catches are approximately 3,000 $t.yr^{-1}$ (Fletcher & Santoro 2010). The mackerel fishery that operates throughout the North Coast, Gascoyne and into the West Coast bioregions has a TAC of 410 $t.yr^{-1}$ of Spanish mackerel plus an additional 180 $t.yr^{-1}$ of grey mackerel (Molony & Lai 2010).

While similar challenges to other West Australian finfish resources and fisheries, the Kimberley region and entire North Coast Bioregion have additional external challenges, including;

1. An absence of baseline information. The recent Montara oil spill highlighted the lack of baseline information in plankton ecology, oceanography and habitat assessments.
2. The monitoring and assessment of finfish resources in the North Coast is logistically challenging. Many areas are remote and areas north of Broome are virtually only accessible by boat. This makes access difficult and, therefore, any field programs resource intensive.
3. There is an increase in the development of land and maritime-based mining activities. This includes coastal developments (*e.g.* port facilities) to support iron ore export and oil and gas exploration and exploitation, with wellheads and pipelines being planned and developed across the Kimberley and Pilbara areas. The direct impacts of coastal or maritime development may include the displacement of commercial and recreational access from certain areas and potentially negative impacts from shipping, dredging, spills and other activities associated with these industries.
4. There is expected to be an increase in permanent and transient populations of people in the northern areas of Western Australia, with estimates in the tens of thousands typically located around the existing population centres (*e.g.* Broome, Port Hedland, Karratha). With more people in the area, there will be more people who will want to undertake recreational fishing activities, with access to fishing highlighted in some of the recruitment advertising. Boat ownership is also likely to be high and this will verified with the recreational fishing from boats to be surveyed in 2011 by the Department of Fisheries. Thus recreational fishing pressure in the North Coast Bioregion will increase. This may be addressed by the Department of Fisheries Western Australia liaising with the Australian Petroleum Production and Exploration Association (APPEA, www.appea.com.au) to highlight and address the limitations of the productivity in the fisheries and these ecosystems, and the need for sustainable fisheries.
5. The Commonwealth Marine Bioregional Planning strategy being led by the Department of Sustainability, Environment, Water, Populations and Communities (SEWPaC [1]) has identified areas in the North Coast that it is considering for inclusion. The spatial management proposed ranges from totally closed areas to general-purpose areas. There will, no doubt, be some closures to areas that are currently open to fishing, which may risk moving existing fishing effort into smaller areas, increasing the risk to sustainability of finfish resources. The alternative is buying out some of this effort although there are few details from the Commonwealth on this option. There is currently only limited ability to restrict recreational effort and catches by the Department of Fisheries.
6. While SEWPaC are putting their Marine Bioregional Planning into effect in waters beyond 3 nautical miles, State Departments, such as the Department of Environment and Conservation (DEC), are also undertaking the planning and establishment of marine parks, which also include areas closed to fishing (*e.g.* Camden Sound). This will have an additive effect of potentially concentrating existing fishing effort into smaller areas.

Regardless, the existing fisheries themselves are sustainable, albeit with somewhat precautionary limits, and the Department of Fisheries Western Australia will continue to liaise with stakeholders and industry to review current management arrangements and potentially develop alternative objectives, strategies and management arrangements to ensure the sustainability of these fisheries in the long term.

While these fisheries may be relatively modest in an Australian and global sense, making these fisheries deliver high quality products and/or experiences in a sustainable way will ensure the viability of these fisheries into the future.

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[1] SEWPaC is the Australian Government's Department that is responsible for Marine Bioregional Planning in Australia. SEWPaC is in the process of identifying marine areas for different levels of protection, potentially including sanctuary zones. See www.environment.gov.au/coasts/mbp/index.html

References

ABARE–BRS 2010 Australian Fisheries Statistics 2009, Canberra.

Caputi N, Fletcher W J, Pearce A & Chubb C F 1996 Effect of the Leeuwin Current on the Recruitment of Fish and Invertebrates along the Western Australian Coast. Marine and Freshwater Research 47: 147–155.

Cresswell G R & Domingues C M 2009 The Leeuwin Current south of Western Australia. Journal of the Royal Society of Western Australia 92: 83–100.

DoFWA 2011 Resource Assessment Framework (RAF) for Finfish Resources in Western Australia. Fisheries Occasional Paper. No. 85. Department of Fisheries, Western Australia.

Emery T, Brown M & Auld S 2009a North West Slope Trawl Fishery Data Summary 2008. Australian Fisheries Management Authority, Canberra.

Emery T, Brown M & Auld S 2009b Western Deepwater Trawl Fishery Data Summary 2008. Australian Fisheries Management Authority, Canberra.

Fairclough D, Lai E & Bruce C 2010 West Coast Demersal Scalefish Fishery Status Report. In: State of the Fisheries and Aquatic Resources Report 2009/10 (eds W J Fletcher & K Santoro). Department of Fisheries, Western Australia, 80–90.

FAO 2009 FAO yearbook Fishery and Aquaculture Statistics 2007. FAO Fisheries and Aquaculture Information and Statistics Service. Rome.

Fletcher W J & Blight S J 1996 Validity of using translucent zones of otoliths to age the pilchard *Sardinops sagax neopilchardus* from Albany, Western Australia. Marine and Freshwater Research 47: 617–624.

Fletcher W J & Santoro K (eds) 2010 State of the Fisheries and Aquatic Resources Report 2009/10. Department of Fisheries, Western Australia.

Gaughan D, Craine M, Stephenson P, Leary T & Lewis P 2008. Regrowth of pilchard (*Sardinops sagax*) stocks off southern WA following the mass mortality event of 1998/99. Final report to Fisheries Research and Development Corporation on Project No. 2000/135. Fisheries Research Report No. 176, Department of Fisheries, Western Australia.

Gaughan D J, Mitchell R W & Blight S J 2000 Impact of mortality, possibly due to herpesvirus, on pilchard *Sardinops sagax* stocks along the south coast of Western Australia in 1998–99. Marine and Freshwater Research 51: 601–612.

Godfrey J S & Ridgway K R 1985 The large-scale environment of the poleward-flowing Leeuwin Current, Western Australia: longshore steric height gradients, wind stresses and geostrophic flow. Journal of Physical Oceanography 15: 481–95.

Jackson G, Norriss J V, Mackie M C & Hall N G 2010 Spatial variation in life history characteristics of snapper (*Pagrus auratus*) within Shark Bay, Western Australia. New Zealand Journal of Marine and Freshwater Research 44: 1–15.

Hesp S A, Potter I C & Hall N G 2002 Age and size compositions, growth rates, reproductive biology and habitats of the West Australian dhufish (*Glaucosoma hebraicum*) and their relevance to the management of this species. Fishery Bulletin, U.S. 100: 214–227.

Hope G S, Peterson J A, Allison I & Radok U (eds) 1976. The Equatorial Glaciers of New Guinea. Results of the 1971–1973 Australian Universities' Expeditions to Irian Jaya: survey, glaciology, meteorology, biology and palaeoenvironments. A. A. Balkema, Rotterdam.

Hopper S D 2009 OCBIL theory: towards an integrated understanding of the evolution, ecology and conservation of biodiversity on old, climatically buffered, infertile landscapes. Plant Soil 322: 49–86.

Lenanton R C, Caputi N, Kangas M & Craine M 2009 The ongoing influence of the Leeuwin Current on economically important fish and invertebrates off temperate Western Australia – has it changed? Journal of the Royal Society of Western Australia 92: 111–127.

Lenanton R C, Fletcher W J & Gaughan D 2007 Integrated Fisheries Management in Western Australia – a significant challenge for fisheries scientists. In: A guide to monitoring fish stocks and aquatic ecosystems (eds Phelan M J and Bajhau H). Australian Society for Fish Biology Workshop Proceedings, Darwin, Northern Territory, 11–15 July 2005. Fisheries Incidental Publication No.25, Northern Territory Department of Primary Industry, Fisheries and Mines, Darwin.

Lenanton R C J, Joll L, Penn J, & Jones G K 1991 The influence of the Leeuwin Current on coastal fisheries of Western Australia. Journal of the Royal Society of Western Australia. 74: 101–114.

McGinley M (topic ed) 2008a Northwest Australian Shelf large marine ecosystem. In: Encyclopaedia of Earth (ed C. J. Cleveland). Environmental Information Coalition, National Council for Science and the Environment (Washington, D. C). http://www.eoearth.org/article/Northwest_Australian_Shelf_large_marine_ecosystem.

McGinley M (topic ed) 2008b Southwest Australian Shelf large marine ecosystem. In: Encyclopaedia of Earth (ed C. J. Cleveland). Environmental Information Coalition, National Council for Science and the Environment (Washington, D. C). http://www.eoearth.org/article/Southwest_Australian_Shelf_large_marine_ecosystem.

McGinley M (topic ed) 2008c West-Central Australian Shelf large marine ecosystem. In: Encyclopaedia of Earth (ed C. J. Cleveland). Environmental Information Coalition, National Council for Science and the Environment (Washington, D. C). http://www.eoearth.org/article/West-Central_Australian_Shelf_large_marine_ecosystem.

McGinley M (topic ed) 2008d North Australian Shelf large marine ecosystem. In: Encyclopaedia of Earth (ed C. J. Cleveland). Environmental Information Coalition, National Council for Science and the Environment (Washington, D. C). http://www.eoearth.org/article/North_Australian_Shelf_large_marine_ecosystem.

Molony B & Lai E 2010 South Coast Purse Seine Fishery Report: Statistics Only. In: State of the Fisheries and Aquatic Resources Report 2009/10 (eds W J Fletcher & K Santoro) Department of Fisheries, Western Australia, 244–245.

Muhling B A, Beckley L E, Gaughan D J, Jones C M, Miskiewicz A G and Hesp S A 2008 Spawning, larval abundance and growth rate of *Sardinops sagax* off southwestern Australia: influence of an anomalous eastern boundary current. Marine Ecology Progress Series 364: 157–167.

Newman S J & Dunk I J 2003 Age validation, growth, mortality and additional population parameters of the goldband snapper (*Pristipomoides multidens*) off the Kimberley coast of northwestern Australia. Fishery Bulletin, U.S. 101: 116–128.

Newman S J, Harvey E S, Rome B M & Skepper C L (in review). Relative efficiency of fishing gears and investigation of resource availability in tropical demersal scalefish fisheries (NDSF). Final report to Fisheries Research and Development Corporation on Project No. 2006/031. Fisheries Research Report, Department of Fisheries, Western Australia.

Newman S J, Skepper C, Mitsopoulos G & McAuley R 2010b North Coast Nearshore and Estuarine Fishery Status Report. In: State of the Fisheries and Aquatic Resources Report 2009/10. (eds W J Fletcher & K Santoro). Department of Fisheries, Western Australia, 165–171.

Newman S J, Skepper C L & Wakefield C B 2010a Age estimation and otolith characteristics of an unusually old, red emperor snapper (*Lutjanus sebae*) captured off the Kimberley coast of north-western Australia. Journal of Applied Ichthyology 26: 120–122.

Newman S J, Wakefield C, Stephenson P, Skepper C, Boddington D, Cliff M, Mitsopoulos G & Rome B 2010c North Coast Demersal Fisheries Status Report. In: State of the Fisheries and Aquatic Resources Report 2009/10. (eds W J Fletcher & K Santoro). Department of Fisheries, Western Australia, 172–189.

Norriss J V & Crisafulli B 2010 Longevity in Australian snapper *Pagrus auratus* (Sparidae). Journal of the Royal Society of Western Australia 93: 129–132.

Nowara G B & Newman S J 2001 A history of foreign fishing activities and fishery-independent surveys of the demersal finfish resources in the Kimberley region of Western Australia. Fisheries Research Report No. 125, Department of Fisheries, Western Australia.

Oxley W C 1904 Report on trawling operations carried out throughout the year 1904. In: The Report on the Fishing Industry for the year 1904 by the Chief Inspector of Fisheries to the Under Secretary, 1st February 1905 (ed C F Gale).

Pearce A F 1991 Eastern boundary currents of the southern hemisphere. Journal of the Royal Society of Western Australia 74: 35–45.

Pearce A, Helleren S & Marinelli M 2000 Review of productivity levels of Western Australian coastal and estuarine waters for mariculture planning purposes. Fisheries Research Report No. 123, Department of Fisheries, Western Australia.

Rodgers M, Sampaklis A & Pham T 2010 Western Deepwater Trawl Fishery. In: 2010. Fishery status reports 2009: status of fish stocks and fisheries managed by the Australian Government (eds D T Wilson, R Curtotti and G A Begg). Australian Bureau of Agricultural and Resource Economics, Bureau of Rural Sciences, Canberra, 337–349.

Sampaklis A, Chambers M & Pham T 2010 North West Slope Trawl Fishery. In: 2010. Fishery status reports 2009: status of fish stocks and fisheries managed by the Australian Government (eds D T Wilson, R Curtotti and G A Begg). Australian Bureau of Agricultural and Resource Economics, Bureau of Rural Sciences, Canberra, 119–130.

Stephenson P & Jackson G 2005 Managing depleted snapper stocks in inner Shark Bay, Western Australia. In: Fisheries assessment and management in data-limited situations (eds G H Kruse, V F Gallucci, D E Hay, R I Perry, R M Peterman, T C Shirley, P D Spencer, B Wilson & D Woodby). Alaska Sea Grant College Programme, Fairbanks, Alaska, 31–50.

Ward T M, Burch P & Ivey A R 2010 South Australian Sardine (*Sardinops sagax*) Fishery: Stock Assessment Report 2010. Report to PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000765-3. SARDI Research Report Series No. 496.

Whittington R J, Crockford M, Jordan D & Jones B 2008 Herpesvirus that caused epizootic mortality in 1995 and 1998 in pilchard, *Sardinops sagax neopilchardus* (Steindachner), in Australia is now endemic. Journal of Fish Diseases 37: 97–105.

Wilson D T, Curtotti R & Begg G A (eds) 2010 Fishery status reports 2009: status of fish stocks and fisheries managed by the Australian Government. Australian Bureau of Agricultural and Resource Economics, Bureau of Rural Sciences, Canberra.

Wise B S, St John J & Lenanton R C (eds) 2007 Spatial scales of exploitation among populations of demersal scalefish: implications for management. Part 1: Stock status of the key indicator species for the demersal scalefish fishery in the West Coast Bioregion. Final report to Fisheries Research and Development Corporation on Project No. 2003/052. Fisheries Research Report No. 163, Department of Fisheries, Western Australia.